Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

Station Paper No. 127

July 1961

Reserve
1.9622
S45t2

Merchantable Cubic-Foot Volume Growth in Natural Loblolly Pine Stands

by

T. C. Nelson, T. Lotti, E. V. Brender,

and K. B. Trousdell

U. S. DEPT. OF AGRICULTURE
SEP 11 1961
CURRENT SERIAL RECORDS

U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Merchantable Cubic-Foot Volume Growth in Natural Loblolly Pine Stands

by

T. C. Nelson, T. Lotti, E. V. Brender, and K. B. Trousdell 1/

INTRODUCTION

This is a second progress report of a regional study on growing space requirements for natural stands of loblolly pine (Pinus taeda L.). It considers cubic-foot growth in relation to age, site, and stand density. The first report of this study was published as Southeastern Forest Experiment Station Paper 97.

The over-all objective of this study is to measure the effects of stand density upon volume production; this report, however, deals only with periodic cubic-foot increment. Stand densities were attained naturally or imposed artificially by cutting over a broad span of ages upon a wide range of sites. It was recognized that one of the most elusive forest management problems has been allocation of reserve growing stock for optimum growth during intermediate stand ages. Most of the approaches to this problem to date have been through thinning studies, and while these studies have provided case histories of the immediate benefits of thinning, they have contributed little to the notion that a stand density for optimum growth may exist for any combination of age and site. Nor have they contributed to the further thought that optimum growing space for a given site and age is capable of being related and translated into economic considerations, such as product objective, maximum earnings, and sound financial policy.

The cubic-foot growth data obtained during the second 5-year growth period of this study are reported in this paper. Obviously, too short a period of record has occurred to allow total production analyses at this time; such analyses require data from additional cutting cycles. This paper, however, provides an addition to our knowledge of the growth relations of natural loblolly pine stands and provides growth predictions which can be translated into stand prescriptions.

1/ T. C. Evans and K. F. Wenger prepared the work plan and amendments for this study. Contributions to planning and analyses by J. L. Clutter and P. C. Guilkey of the Southeastern Forest Experiment Station staff are gratefully acknowledged.

METHODS

Circular $\frac{1}{4}$-acre plots with $\frac{1}{2}$-chain isolation strips were established in 152 plots in four widely separated locations representing a wide range of site indices, stand densities, and ages. Plots were selected originally in 20- to 60-year-old stands with a range in site index of slightly less than 60 feet to more than 100, and a uniformity of site index that did not vary more than 10 feet within the plot boundaries. Densities ranged from 40 to 130 percent of full stocking (density percent [2]) (6). Stands were rejected if the loblolly pine was not essentially pure, undisturbed, even-aged, uniformly spaced, and insect and disease free.

Plots were established in Georgia on the Hitchiti Experimental Forest in the lower Piedmont, in South Carolina on the Santee Experimental Forest and the Westvaco Experimental Forest, [3] both locations in the lower coastal plain, and in Tidewater, Virginia, on the Camp Experimental Forest [4] during 1948-1950.

All pine stems 0.6 inch d. b. h. and larger were tallied to the nearest tenth-inch in diameter. Hardwoods 4.6 inches d. b. h. and larger, predominantly in stand understories, were eliminated by poisoning. Site index was determined by conventional site index measurements, using Coile's (2) site index curves. Earlier data from the Hitchiti, Santee, and Camp Experimental Forests provided volume tables which were used in computing merchantable cubic-foot volume outside bark of stems to a 4-inch top diameter outside bark for trees 4.6 inches d. b. h. and larger.

Approximately one-third of the plots were cut to specified residual densities immediately following plot establishment. It was necessary to modify the thinning method (from below) somewhat in order to obtain uniform spacing of residual stems and to remove undesirable trees in all crown classes. Thus, clustering was minimized and each tree occupied a growing space commensurate with its size class under the stocking regime assigned to the plot.

The thinned plots were rethinned as necessary to keep them in the same density class and another one-third received an initial thinning at the end of the first 5-year growth period. The distribution of plots at the beginning of the second 5-year growth period by age, site, and stand density is shown in tables 1 and 2. All plots were remeasured following the fifth and

---

2/ Density percent expresses the basal area of a stand of given average diameter as a percentage of the basal area of well-stocked stands of the same average diameter.

3/ Maintained by the West Virginia Pulp and Paper Company near Georgetown, S. C.

4/ Maintained in Sussex County, Virginia, by the U. S. Forest Service, in cooperation with the Union Bag-Camp Paper Corporation.

Table 1. --Distribution of thinned plots at beginning of second five-year period according to site index, age, and density percent

Site index (feet)	Age class	Density percent								
		11 to 20	21 to 30	31 to 40	41 to 50	51 to 60	61 to 70	71 to 80	81 to 90	91 to 100
	Years	Plots								
60	21 to 30	--	--	--	--	1	--	--	--	--
	31 to 40	--	1	3	2	--	1	3	1	--
	41 to 50	--	1	--	3	1	1	1	--	--
	51 to 60	--	2	--	--	2	--	--	--	--
	61+	--	--	--	--	1	--	--	--	--
70	21 to 30	--	1	1	1	--	1	--	--	--
	31 to 40	1	2	1	--	1	1	3	1	--
	41 to 50	--	--	1	--	1	--	--	--	--
	51 to 60	1	1	1	2	2	1	--	--	--
	61+	--	--	--	--	--	1	--	--	--
80	21 to 30	--	1	1	1	--	1	--	--	--
	31 to 40	1	2	2	--	1	1	3	1	--
	41 to 50	--	--	1	--	1	--	--	--	--
	51 to 60	1	1	1	2	2	1	--	--	1
	61+	--	--	--	--	--	1	--	--	--
90	21 to 30	--	--	--	1	--	1	1	--	--
	31 to 40	--	--	1	--	1	--	--	--	--
	41 to 50	--	1	--	--	2	1	2	--	--
	51 to 60	--	--	1	1	1	1	2	1	--
	61+	--	--	--	--	--	--	--	--	--
100	21 to 30	--	--	1	--	1	1	1	--	--
	31 to 40	--	--	--	1	--	--	--	1	--
	41 to 50	--	--	--	--	1	--	--	--	--
	51 to 60	--	--	--	--	1	1	--	--	--
	61+	--	--	--	--	--	--	--	--	--

Table 2. --Distribution of unthinned plots at beginning of second five-year period according to site index, age, and density percent

Site index (feet)	Age class	Density percent							
		41 to 50	51 to 60	61 to 70	71 to 80	81 to 90	91 to 100	101 to 110	111 +
	Years	Plots							
60	21 to 30	--	--	--	--	--	--	--	--
	31 to 40	1	--	--	4	1	1	--	--
	41 to 50	--	--	--	2	--	--	--	--
	51 to 60	--	--	2	1	1	--	--	--
	61+	--	--	2	2	--	--	--	--
70	21 to 30	--	--	--	--	1	--	--	--
	31 to 40	--	--	--	1	--	--	--	--
	41 to 50	--	--	--	--	1	--	1	--
	51 to 60	--	--	--	--	1	--	--	--
	61+	--	--	1	--	--	1	--	--
80	21 to 30	--	2	1	1	--	--	1	--
	31 to 40	--	--	1	--	2	--	--	1
	41 to 50	--	--	1	1	--	--	1	--
	51 to 60	--	--	--	--	--	1	--	--
	61+	--	--	--	--	1	--	--	--
90	21 to 30	--	--	--	1	--	--	--	1
	31 to 40	--	--	--	--	--	--	--	--
	41 to 50	--	--	2	--	--	--	--	--
	51 to 60	--	--	--	2	--	--	--	--
	61+	--	--	--	--	--	--	--	--
100	21 to 30	--	--	--	--	--	--	--	--
	31 to 40	--	--	--	--	--	--	--	--
	41 to 50	--	--	1	1	1	--	--	1
	51 to 60	--	--	--	--	--	1	--	--
	61+	--	--	--	--	--	--	--	--

tenth growing seasons. Growth was expressed as merchantable net periodic annual increment and the initial screening of all 511 combinations of the independent variables for an estimating equation was fitted to the following form:

$$Y = b_0 + b_1(1/A) + b_2(S) + b_3(D) + b_4(D^2) + b_5(S/A) + b_6(D/A) + b_7(D^2/A) + b_8(SD) + b_9(SD^2)$$

Where Y = periodic 5-year net annual merchantable growth in cubic feet per acre of trees 4.6 inches d.b.h. and larger

A = age of stand in years at the beginning of the 5-year period
S = site index of stand
D = density of the stand
b with subscripts = coefficients derived from the data

RESULTS

Thinned Stands

Analyses of the 5- to 10-year growth data have confirmed many of Wenger's results (7). In the thinned stands, cubic-foot growth was related to age, site index, and stand density expressed as density percent (6) and as basal area per acre. Table 3 shows basal area equivalents for a wide range of density percents.

Table 3.--Basal areas per acre in relation to percent of theoretical full stocking for various diameter classes

Average d.b.h. (inches)	Percent stocking											
	20	30	40	50	60	70	80	90	100	110	120	130
	Square feet per acre											
4	24	36	47	59	71	83	95	107	119	131	142	154
6	28	42	56	70	86	98	112	126	140	154	168	182
8	31	46	61	77	92	107	122	138	153	168	183	199
10	32	48	64	81	97	113	129	145	161	177	193	210
12	33	50	67	84	100	117	134	150	167	184	201	217
14	34	52	69	86	103	120	138	155	172	189	206	223
16	35	53	70	88	105	123	140	158	175	193	210	228

Using density percent as an expression of stand density, the relations of growth in cubic feet per acre to stand age, site index, and stand density were as follows:

(Equation 1)

$$\text{Cubic-foot growth} = 205.0 + 0.26005\left(\frac{10{,}000}{\text{Age}}\right) - 0.03087(\text{Density Percent})^2$$

$$+ 0.05824(\text{Site} \times \text{Density Percent}) - 8.11990(\text{Site}) + 0.05328(\text{Site})^2$$

Where density = percent of theoretical full stocking after thinning at the beginning of the 5-year period

Of the nine independent variables screened in the original equation, only the first three expressed in Equation 1 proved significant. The last two terms in the equation were added to eliminate curvilinearity of residuals when plotted in relation to site. This expression explained over 78 percent of the variation in annual cubic-foot growth. Results are shown in table 4 and expressed graphically in figure 1.

Table 4. --Relation of periodic annual cubic-foot growth to age, site, and density percent, in thinned stands

Age	Density percent								
	20	30	40	50	60	70	80	90	100
	Cubic feet								
SITE 60									
30	--	--	87	94	95	90	78	61	
40	--	--	65	72	73	68	57	39	
50	--	--	52	59	60	55	44	26	
60	--	--	43	51	52	46	35	18	
SITE 70									
30	--	79	98	111	118	118	113	101	
40	--	57	76	89	96	97	91	80	
50	--	44	63	76	83	84	78	67	
60	--	36	55	68	75	75	70	58	
SITE 80									
30	64	95	120	139	151	158	158	152	140
40	42	73	98	117	130	136	137	131	119
50	29	60	85	104	117	123	124	118	106
60	21	52	77	96	108	115	115	109	97
SITE 90									
30	85	122	153	177	196	208	214	214	208
40	63	100	131	156	174	186	193	192	186
50	50	87	118	143	161	173	180	179	173
60	42	79	109	134	153	165	171	171	165
SITE 100									
30	117	159	197	226	251	269	281	287	286
40	95	138	175	205	229	247	259	265	265
50	82	125	162	192	216	234	246	252	252
60	73	116	154	183	208	226	238	243	243

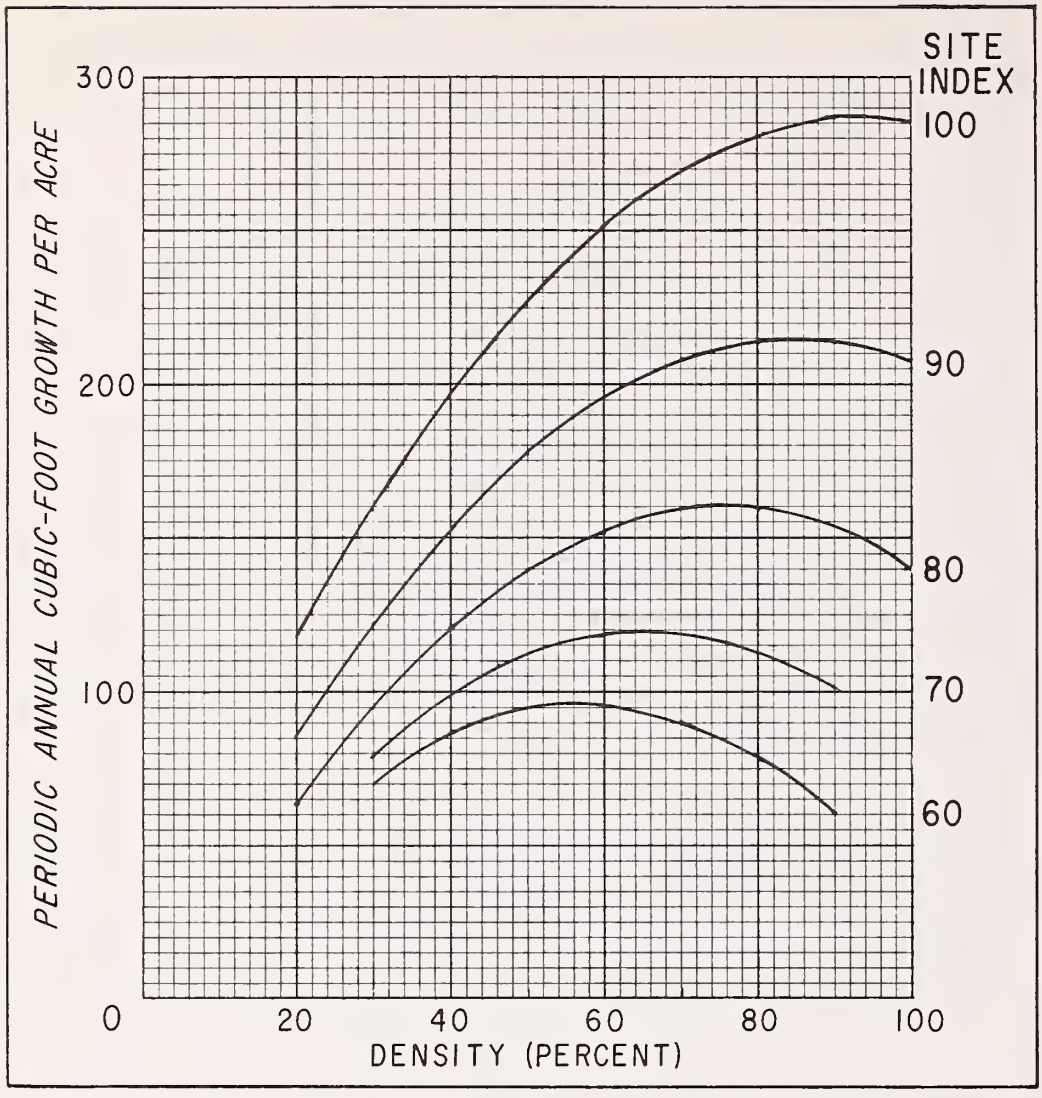

Figure 1. --Relation of periodic annual cubic-foot growth in thinned stands to age, site, and density percent at age 30.

We were also able to explain over 78 percent of the variation in annual cubic-foot growth using basal area per acre after thinning as an expression of stand density. The relationship of growth to site index, stand age, and basal area was as follows:

(Equation 2)

$$\text{Cubic-foot growth} = 148.85409 + 0.28630\left(\frac{10{,}000}{\text{Age}}\right) + 0.0358(\text{Basal Area} \times \text{Site}) - 0.012(\text{Basal Area})^2 - 6.79599(\text{Site}) + 0.04451(\text{Site})^2$$

Where basal area = basal area per acre of all stems 0.6 inch d. b. h. and larger after thinning at the beginning of the 5-year period.

The results are shown in table 5 and figure 2.

The similarity of these separate analyses is quite apparent. The curvilinearity of the site-density relationships to cubic-foot growth is clearly illustrated in figures 1 and 2. The effect of age is apparent in Equations 1 and 2.

Table 5. --Relation of periodic annual cubic-foot growth to age, site, and basal area, in thinned stands

Age	Square feet basal area per acre													
	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cubic feet													
SITE 60														
30	--	--	74	82	88	92	93	91	88					
40	--	--	50	59	64	68	69	68	64					
50	--	--	36	44	50	54	55	53	50					
60	--	--	27	35	41	44	45	44	40					
SITE 70														
30	--	68	82	94	103	110	115	117	117	114	110			
40	--	44	58	70	79	86	91	93	93	91	86			
50	--	30	44	56	65	72	77	79	79	76	71			
60	--	20	34	46	56	63	67	70	70	67	62			
SITE 80														
30	60	81	99	114	127	138	146	152	155	156	155			
40	37	57	75	90	103	114	122	128	131	132	131			
50	22	43	60	76	89	100	108	114	117	118	117			
60	13	33	51	66	80	90	98	104	108	109	107			
SITE 90														
30	79	103	124	143	160	174	186	195	202	207	209	209	206	201
40	55	79	100	119	136	150	162	172	179	183	185	185	183	178
50	41	65	86	105	122	136	148	157	164	169	171	171	168	163
60	31	55	77	96	112	127	138	148	155	159	162	161	159	154
SITE 100														
30	106	134	159	181	201	219	235	248	258	266	272	276	277	275
40	83	110	135	158	178	196	211	224	235	242	249	252	253	252
50	68	96	120	143	163	181	196	210	220	228	234	238	238	237
60	59	86	111	134	154	172	187	200	211	218	225	228	229	228

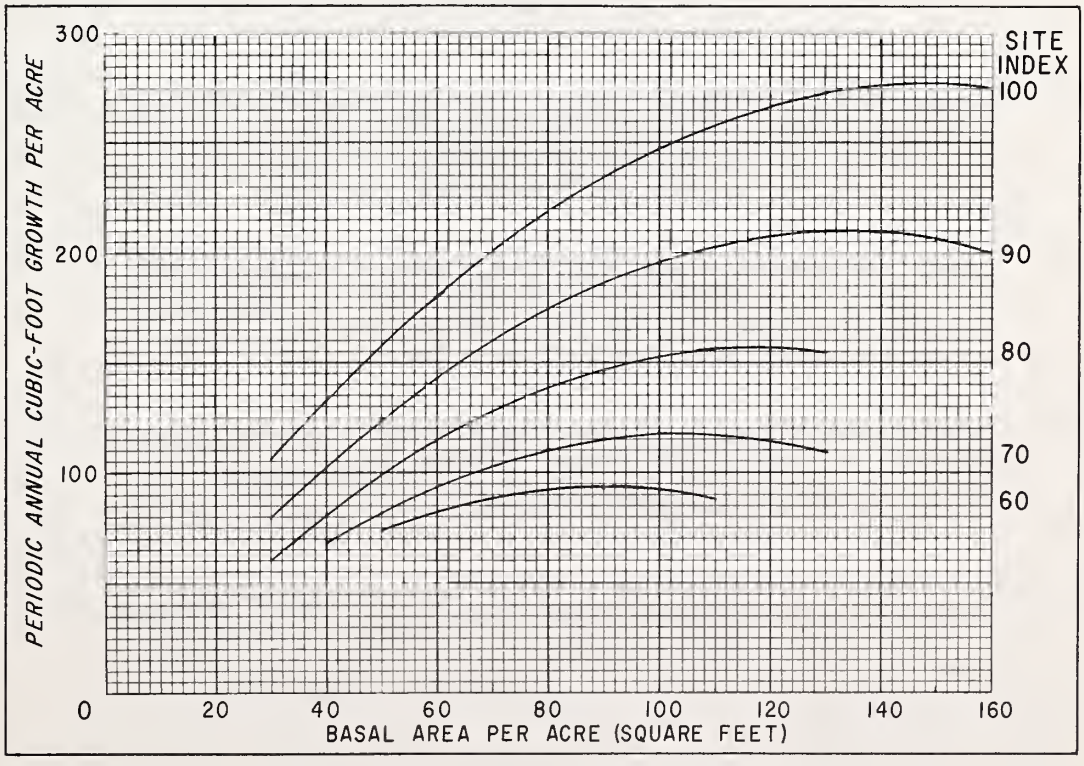

Figure 2. --Relation of periodic annual cubic-foot growth in thinned stands to age, site, and basal area at age 30.

Unthinned Stands

In the unthinned stands, the only measure of stand density used in relation to cubic-foot growth was density percent, because of success with this measure in past analyses. The relation of growth in cubic feet per acre to site index, stand age, and density percent in the unthinned stands was as follows:

(Equation 3)

$$\text{Cubic-foot growth} = -103.99189 + 0.31055\left(\frac{10{,}000}{\text{Age}}\right) - 0.02553(\text{Density Percent})^2 + 0.05158(\text{Site} \times \text{Density Percent})$$

Where density = percent of theoretical full stocking at the beginning of the 5-year period

The coefficient of determination for this expression was approximately 76 percent. The results are shown in table 6 and figure 3.

Although the coefficient of determination is not as high as the corresponding equation in thinned stands, similar curve shapes, a site-density interaction, significant effects of age and site, and culmination of growth at higher densities on high sites than on low sites are also apparent in the unthinned stands.

Table 6. --Relation of periodic annual cubic-foot growth to age, site, and density percent, in unthinned stands

Age	Density percent									
	20	30	40	50	60	70	80	90	100	110
	Cubic feet									
SITE 60										
30	51	69	82	90	93	91	84	71	54	
40	25	44	57	65	67	65	58	45	28	
50	10	28	41	49	52	50	42	30	12	
60	0	18	31	39	42	39	32	20	2	
SITE 70										
30	61	85	103	116	124	127	125	118	105	
40	36	59	77	90	98	101	99	92	79	
50	20	43	62	75	83	86	84	76	64	
60	10	33	51	65	73	76	73	66	54	
SITE 80										
30	72	100	124	142	155	163	166	164	157	
40	46	74	98	116	129	137	140	138	131	
50	30	59	82	101	114	122	125	123	115	
60	20	49	72	90	104	112	115	112	105	
SITE 90										
30	82	116	144	168	186	199	207	210	208	201
40	56	90	118	142	160	174	182	185	183	175
50	41	74	103	126	145	158	166	169	167	160
60	30	64	93	116	134	148	156	159	157	150
SITE 100										
30	92	131	165	194	217	235	249	257	260	258
40	67	105	139	168	191	210	223	231	234	232
50	51	90	124	152	176	194	207	216	219	217
60	41	80	113	142	165	184	197	205	208	206

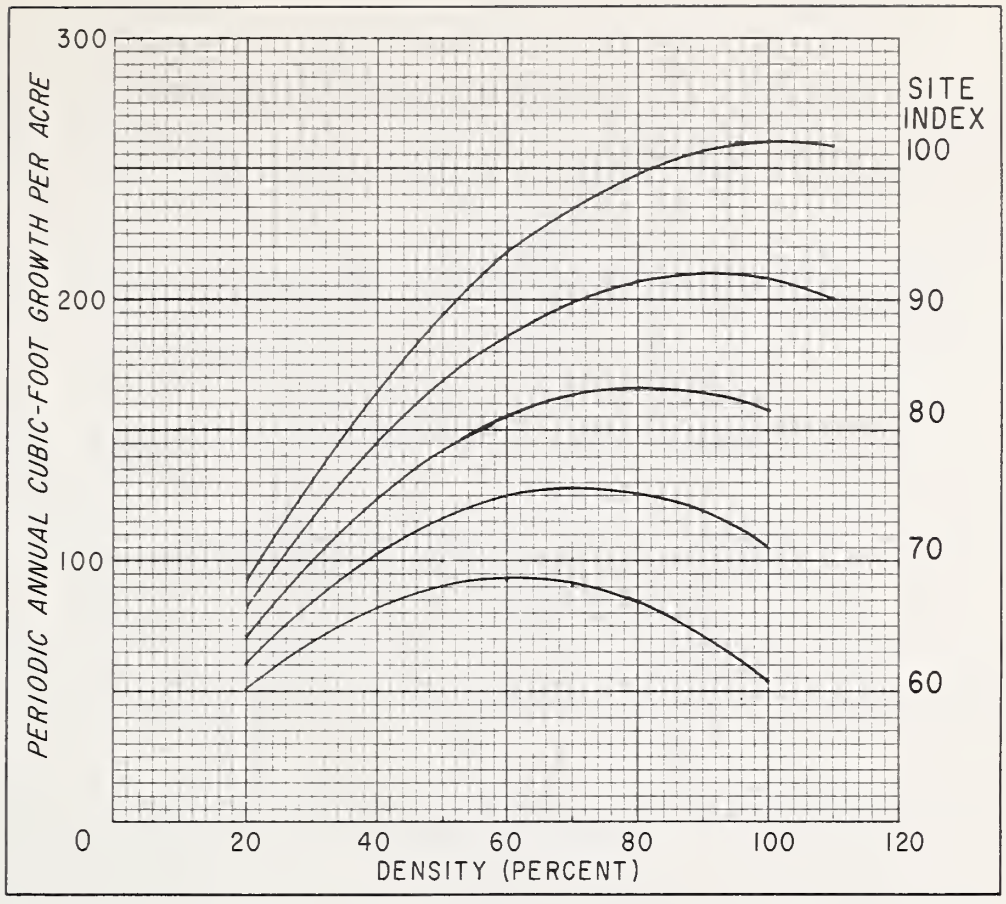

Figure 3. --Relation of periodic annual cubic-foot growth in unthinned stands to age, site, and density percent at age 30.

DISCUSSION

Wenger et al. (7) discussed the results of this study at the end of 5 growing seasons. They concluded that cubic-foot volume growth was significantly related to site index and residual density after thinning. Cubic-foot volume growth was also significantly related to age as well as site index and density of unthinned stands. However, no curves or optimum densities were apparent then and none of their equations accounted for more than 40 percent of the variation in growth.

The coefficients of determination obtained in this study during the second 5-year growth period (75 to 80 percent) are high enough to provide reasonable predicting accuracy. For example, the standard error of estimate for Equation 1 is ± 38 cubic feet at the mean. Some of the factors which perhaps account for the unexplained error include mortality, diameter distribution, less than full use of growing space for a short period following the heavier thinnings, genetic variation, clustering, climatic differences, and measurement error.

The tabular and graphic values presented in this paper have two principal uses for the practicing forester, as a prediction mechanism and as a prescription tool.

The forester using these tables as a prediction mechanism must develop a scale-down factor for his individual holdings before the growth predictions are meaningful. The growth predicting equations were developed under ideal natural conditions and approach the maximum growth values obtainable from natural loblolly pine under any given age, site, and stand density combination unless cultural measures are instigated which, in effect, change the site. The plots represented in these analyses are more uniform than can be expected in entire forest management units, clustering is minimized, and normal deterrents to growth that are present in forest units larger than $\frac{1}{4}$ acre were absent from the sources of these data.

The same characteristics which make scale-down necessary for growth predictions, however, enhance the value of the results for prescription purposes. They provide guides for forest management under conditions that approach the goal of most forest managers of loblolly pine; i.e., units of uniform site, condition classes and spacing in pure loblolly pine, vigorous stands, and disease- and insect-free stems. Thus the levels of age, site, and stocking at which growth changes occur closely approach absolute values that are logical goals and guides and are indeed meaningful in forest management planning.

The culmination of growth at low densities on low sites and high densities on high sites was expected. Gruschow and Evans (3) obtained similar curve shapes in their work in young slash pine stands, and McClay (4) had indications of the same relationship in partially cut 25- to 35-year-old loblolly pine.

The management implications of this conclusion are quite broad. They indicate that the forest manager should retain a higher basal area on good sites than on poor sites if his management goal is to produce maximum merchantable cubic-foot growth. For example, differentiating Equation 2 with respect to basal area indicates that merchantable cubic-foot growth culminates at a total basal area per acre stocking of approximately 90 square feet at Site Index 60 and at approximately 150 square feet per acre at Site Index 100.

The results of this study disagree with the European idea that growth does not reach an optimum within its natural limits of stocking (5). The current study shows culmination of the growth curves, although relatively flat curve forms result that indicate that a wide range of stocking can be maintained while still producing 90 percent of optimum growth.

The flat curve form over a wide range of stocking gives the forest manager an additional tool in forest regulations; it provides him with a sound basis to store volume on the stump and reduces disparities in operations occasioned by uneven distribution of age classes. It also indicates that he has a wider range of stocking levels than previously recommended which will produce near equal volumes of growth, thus giving him a choice of a wider range in alternative rates of return. With overlapping stocking levels at near optimum growth rates for successive site index classes, not much loss in growth can accrue because of relatively imprecise site classifications.

The growth levels of the thinned and unthinned stands show little or no difference at the same stocking level. Mathematically, there is no significant difference between comparable expressions. Biologically, on the good sites, there is an indication that thinning increases effective stocking and subsequently growth for a given stocking level, perhaps by elimination of moribund trees that add to the stocking level value but do not appreciably add growth. We interpret the similarity between growth in thinned and unthinned stands to indicate that there has been little shock effect and that the thinned stands have been able to regain full utilization of growing space with rapidity following thinning from below. Any reduction in growth during the 5-year period in the thinned stands was not greater than the reduction in the unthinned stands occasioned by limited mortality.

There was considerable similarity between the results of this study and the Hitchiti compartment study reported by Brender in "Growth predictions for natural stands of loblolly pine in the lower Piedmont" (1). The Hitchiti study also produced relatively flat curve forms.

The progressive culmination of growth at higher levels of stocking as site increases was evident in both studies. Stocking levels at growth culmination, however, were higher in the stand density study than in the Hitchiti study. Part of this difference can be explained by differences in the measurement of stocking levels; total basal area of stems 1.0 inch d. b. h. and larger entered the stocking value in this study, whereas only stems 5.6 inches d. b. h. and larger were present in the Hitchiti measure of stocking. Also, the smaller, uniform plot size in the stand density study minimized the effect of clustering within plots and eliminated much of the variation in site and density within plots--factors not linear in their expression.

SUMMARY

A series of 153 plots were selected in 20- to 60-year-old stands of natural loblolly pine of a wide range in site index and density in Georgia, South Carolina, and Virginia. Approximately one-third of these plots were thinned to a range of residual densities at the time of plot establishment. These plots were rethinned and another one-third received their first thinning at the end of the first 5-year growth period. This paper discusses the results of analyses of the 5- to 10-year cubic-foot volume growth.

In the thinned stands, cubic-foot volume growth was found to be significantly related to age, site, and density expressed as density percent and total basal area per acre:

(Equation 1)

$$\text{Cubic-foot growth} = 205.0 + 0.26005\left(\frac{10{,}000}{\text{Age}}\right) - 0.03087(\text{Density Percent})^2 + 0.05824(\text{Site} \times \text{Density Percent}) - 8.11990(\text{Site}) + 0.05328(\text{Site})^2$$

$$R^2 = 0.781$$

(Equation 2)

$$\text{Cubic-foot growth} = 148.85409 + 0.28630\left(\frac{10{,}000}{\text{Age}}\right) + 0.0358(\text{Basal Area} \times \text{Site}) - 0.012(\text{Basal Area})^2 - 6.79599(\text{Site}) + 0.04451(\text{Site})^2$$

$$R^2 = 0.781$$

In the unthinned stands, cubic-foot growth was related to age, site, and density percent in the following formula:

(Equation 3)

$$\text{Cubic-foot growth} = -103.99189 + 0.31055\left(\frac{10{,}000}{\text{Age}}\right) - 0.02553(\text{Density Percent})^2 + 0.05158(\text{Site} \times \text{Density Percent})$$

$$R^2 = 0.761$$

A progressive culmination of growth at higher levels of stocking as site increases is evident in all three expressions. The relatively flat growth curves in relation to density with a culmination point show that the forest manager has a wide range of stocking levels available without appreciable loss in merchantable cubic-foot growth.

LITERATURE CITED

(1) Brender, E. V.
1960. GROWTH PREDICTIONS FOR NATURAL STANDS OF LOBLOLLY PINE IN THE LOWER PIEDMONT. Ga. Forest Res. Council Rpt. 6, 7 pp., illus.

(2) Coile, T. S.
1952. SOIL PRODUCTIVITY FOR SOUTHERN PINES. PART I. SHORTLEAF AND LOBLOLLY PINES. Forest Farmer 11(7): 10-11, 13.

(3) Gruschow, G. F., and Evans, T. C.
1959. THE RELATION OF CUBIC-FOOT GROWTH TO STAND DENSITY IN YOUNG SLASH PINE STANDS. Forest Sci. 5: 49-55.

(4) McClay, T. A.
1955. THE RELATION OF GROWTH TO SITE AND RESIDUAL DENSITY OF LOBLOLLY PINE PULPWOOD STANDS. U. S. Forest Serv. Southeast. Forest Expt. Sta. Res. Notes 78, 2 pp., illus.

(5) Möller, Carl Mar.
1954. THE INFLUENCE OF THINNING ON VOLUME INCREMENT. In Thinning problems and practices in Denmark. N. Y. State Col. Forestry, Syracuse Univ. Tech. Paper 76, 92 pp.

(6) Stahelin, R.
1949. THINNING EVEN-AGED LOBLOLLY AND SLASH PINE STANDS TO SPECIFIED DENSITIES. Jour. Forestry 47: 538-540.

(7) Wenger, K. F., Evans, T. C., Lotti, Thomas, Cooper, R. W., and Brender, E. V.
1958. THE RELATION OF GROWTH TO STAND DENSITY IN NATURAL LOBLOLLY PINE STANDS. U. S. Forest Serv. Southeast. Forest Expt. Sta. Paper 97, 10 pp., illus.

NATIONAL AGRICULTURAL LIBRARY
1022591219

* NATIONAL AGRICULTURAL LIBRARY
1022591219